InLCA: Life Cycle Inventory Development

Life Cycle Inventory Analysis – A Case Study of Steel Used in Brazilian Automobiles

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Abstract

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Data acquisition to perform LCA is time and capital consuming. There is already international data about environmental aspects in several processes. This study aims to verify the possibility of adapting international data to Brazilian conditions. Therefore, a Life Cycle Inventory was conducted to compare the use of national and international data for steel used in automobiles. This was done in three steps: objective and scope definition, inventory analysis and interpretation. LCI is a simplification of Life Cycle Assessment (LCA) as impact assessment is not taken into account. Even so, LCI takes into account all life cycle stages of a product, that is, from its extraction through its deposition. In this study, three phases of the life cycle were considered: steel manufacturing, automobile use and disposal. In the case studied, the amount of steel evaluated was 263 kg, which would be possible to be replaced by other materials in a 1,300 kg automobile. Resources and energy consumption, atmospheric emissions and solid residues production were taken into account within the analysis done. Results show that automobile use and materials manufacturing are responsible for the bulk of energy and resources consumption. Solid residues occur mainly in the discard phase, due to the low level of recycling. Several differences were also achieved between national and international data, which implies the need of environmental databases development.

Keywords: Automobile; life cycle assessment; steel, recycling

Introduction

Life Cycle Assessment (LCA) is a tool to evaluate environmental impacts through the life cycle of a product, that is, from resources extraction to final product disposition [1]. Several studies divide this methodology in four interrelated steps: aim and scope definiton, inventory analysis, impact analysis and improvement analysis [1–3]. The latter is known by ISO [4] as an interpretation step and is linked to all the other steps.

Data acquisition to perform LCA is time and capital consuming. There is already international data about environmental aspects in several processes. Therefore, the aim of this study is to to verify the possibility of adappting basic international data to Brazilian conditions. In order to achieve this aim, it was performed a Life Cycle Inventory comparison between the use of national and international data for steel used in automobiles.

Due to the large amount of data necessary to develop an LCA, a preliminary evaluation (PE) was performed as shown in **Fig. 1** to help define the scope of the study. The goals of the PE were to identify environmental impacts in the life cycle of automobiles and evolution in automobile production, mainly those related to new materials and fuels.

In the course of this evaluation it was found out that, worldwide, the automobile industry is responsible for the consumption of 20% of steel, 10% of aluminium [7], 7% of plastics [8] and 75% of casted magnesium [9]. Additionally, it was observed that from 1978 to 2001 there was a 5.2% decrease on the automobile weight in average in the USA [7]. The same authors reported that in 2001 the share of steel in an average US car was 40.8% of conventional steel, 10.6% of high-strength steel, and 2.4% of other steels. Despite a decreasing tendency during this period, on a mass basis steel is still the most used material in automobiles.

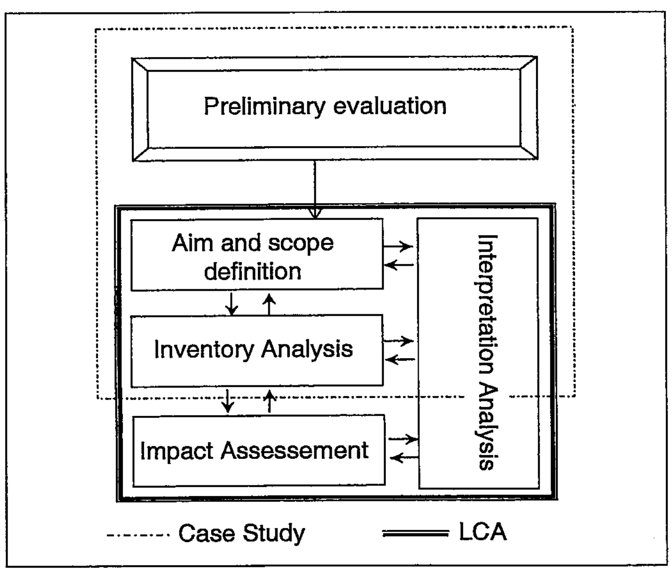

Fig. 1: Life cycle case study

Table 1: Environmental aspects and impacts in automobile life cycle

Life Cycle Steps	Environmental aspects or impacts				
	Resources consumption		Into the air	Into the water	Into the soil
Resources extraction and transportation	*Surface*	Land use[3]	Particulate matter[3] CO[4, 11, 12], CO_2[4, 11, 12, 13], H_2O, NO_X[4, 12, 13, 14], SO_X[11, 12], HC[4, 11, 12], Pb, Noise, NH_3	Acidification[1, 2, 26] Biodiversity change[1, 26] Heavy metals[2] Toxic releases[2] Pb[14], As[14], Cd[14], Halons[14], Benzene[14], Gasoline[14]	Arid soils[1, 26] Deepen soil[3] Underwater leakage[4] Soil empoverishment[4]
	Underground	Energy[3]			
Materials processing	Water consumption[3, 12]		Particulate matter[5, 6, 7, 11] CO_2[6, 7, 8, 9, 11, 12, 13], CO[6, 7, 8, 9, 11, 12], SO_x[5, 6, 7, 8, 9, 11, 12], NO_x[5, 6, 7, 11, 12], HC[5, 6, 7, 11, 12], HCL[8, 9], HCN[8, 9], NH_3[8, 9], fluorides[8, 9], CF_4[10], C_2F_6[10]	DBO[5], Oil and grease[5, 8, 9], Solids[5], As[5], Cr[5], Pb[5], Hg[5], Cd[5], Fenols[5], Toxic releases[4]	–
Automobile assembly	Water consumption Energy consumption		–	–	–
Use	Energy consumption[11, 12, 13] Water consumption[12]		Particulate matter[11], CO[4, 11, 12], CO_2[4, 11, 12, 13], H_2O, NO_X[4, 12, 13, 14], SO_X[11, 12], HC[4, 11, 12], Pb, Noise, NH_3	–	Solid residues (tires, filters, oils, batteries) Land use[16, 19, 20]
Discard*	–		–	–	ASR[4, 18, 22, 23] Steel[21] Aluminium[21] Tires[21, 25] Batteries[24]

– No recycling case
[1][10]; [2][11]; [3][12]; [4][13]; [5][14]; [6][15]; [7][16]; [8][17]; [9][18]; [10][19]; [11][20]; [12][21]; [13][22]; [14][23]; [15][24]; [16][25]; [17][26]; [18][27]; [19][28]; [20][29]; [21][30]; [22][31]; [23][32]; [24][33]; [25][34]; [26][35]

Regarding environmental aspects and environmental impacts of the automobile life cycle, **Table 1** presents a summary of information gathered from several studies [10–35]. Results suggest that the most important issues are water and energy consumption (mainly in materials processing and use stages), solid residues (mostly caused by automobile discard) and atmospheric emissions (mainly during the combustion process).

1 Case Study – Steel Used in Automobiles Produced in Brazil

1.1 Aim and scope definition

Based on average US figures, previously presented, it was assumed that a typical automobile of 1,300 kg has 878 kg of steel and that 30 per cent of this material, i.e., 263 kg, can be substitute by other materials.

Regarding the life-cycle assessment, three phases were considered, as shown in **Fig. 2**. The materials production (either primary or secondary), the use of the automobile and its discard. The analysis was restricted to Brazil and the collected data were from the year 1998.

The Brazilian motor vehicle and automotive parts industry consumed respectively 1,567 and 2,024 thousands of tons of steel in 1996 and 2002, which accounted for 12.4% and 12.8% of the national production, respectively [36–37].

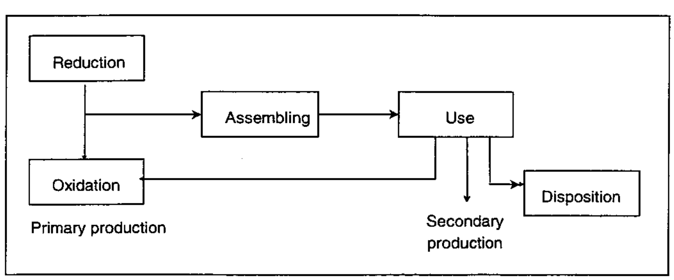

Fig. 2: Life cycle stages

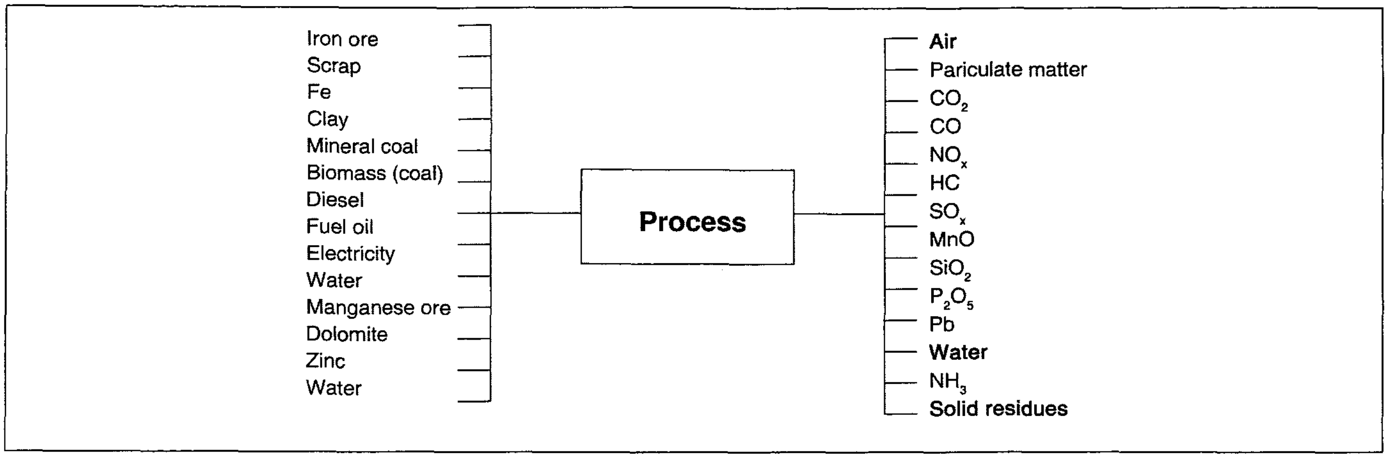

Fig. 3: Inputs and outputs collected

Fig. 3 shows inputs (on the left side) and outputs (on the right side) according to the preliminary analysis and the data availability.

1.2 Inventory analysis

The data of the inputs and outputs shown in Fig. 3 were collected for each life-cycle stage and stored in electronic worksheets. Whenever data was not available, theoretical mass balances were performed or the worst scenario was used. For example, emissions were assumed to be just equal to the legal allowable limit.

1.3 Brazilian data of steel manufacturing

Primary steel is produced through two main processes: reduction and oxidation. There are several ore reduction processes, but in Brazil the most common is based on high furnaces, technology that is used by the main four Brazilian steel mills [38–41]. Altogether, these four mills accounted for 60% of the national steel production in 1999.

MME [37] presents in its Annuary the steel production in Brazil and total raw materials consumption of national steel manufacturing: coking coal, charcoal, iron ore, manganese ore, iron and steel scrap, fuel oil, electric power, Diesel fuel, ferroalloys, pig iron, dolomite, zinc, limestone, sponge iron, fluorite, Tin, lead, aluminium and electrodes.

In the National Energy Balance [47] figure Brazilian pig iron and steel energy consumption: natural gas, steam and metal coal, Diesel oil, fuel oil, LPG, kerosene, gas coke, coal coke, electricity, charcoal, other secondaries of petroleum and bitumen, which accounted with 581 GJ in 1998.

Water consumption and PM was obtained from industries. As far as high furnace operation is concerned, the main pollutants are the slag and emissions of particulate matter and of other combustion gases (CO, CO_2, HC, SO_x, NO_x). Both coke from coal and charcoal are used in Brazil as carbon sources for the ore reduction [42]. There are differences from the slag produced when coke from coal or charcoal are used. Silva [43] states that about 700 to 800 g emitted per kilogram of steel produced when coke is used. This emission is reduced down to 490 g/kg of steel when charcoal is used.

Campos Fo [44] presents the main reactions that occur in these furnaces. Considering that (1) the iron content in the ore is 50% and (2) half of the steel is produced from hematite and half from magnetite, the production of 1 kg of cast iron requires 0.72 kg of Fe_2O_3, 0.69 kg of Fe_3O_4 and 0.3 kg of carbon. Nevertheless, the actual amount of coke and charcoal used sums up 0.64 kg [37].

Cast iron is further oxidized in order to reduce the content of C, Si, Mn, S and P in cast iron. In Brazil, oxidation is performed mostly in oxygen converters. According to the reactions shown by Silva and Mei [45] and Campos Fo [44], there are emissions of CO, SiO_2, MnO, SO_2 e P_2O_5. Considering the minimum amount of the chemical elements (C, Si, Mn, S e P) in the cast iron and the steel, the theoretical emission per kilogram of steel are 72.3 g of CO; 0.24 g of SiO_2; 6.74 g of MnO; 1.92 g of SO_2 and 10.90 g of P_2O_5.

Assuming that each 1,035–1,109 g of cast iron results in one kg of steel, due to the oxidation, 1,419–1,449 g of iron ore are required to produce 1 kg of steel.

2 International Data

International data was obtained from IISI [53], however only for water consumption, particulate matter and NO_x emissions in the air and solid residues production.

US data of steel production were obtained from the software TEAM of Ecobilan [54], which is quite different from Brazilian ones. Some data were not collected in the national case: lubricating, aldeyd, fluoride, ammonia, acid and metals emissions in air, wastewater emissions and detailed information about solid residues. On the other hand, there are estimatives about national emissions of MnO, P_2O_5 and SiO_2. The US data was from 1995.

In order to compare, it was only considered data that was available in both datasets (**Table 2**).

Table 2: US Data per Kilogram of Steel Produced (1995)

Input / Output	Unit	Primary steel	Secondary steel	Primary (83%) and Secondary (17%)
Water	l	82.2924	1.1912	68.505196
Coking coal	kg	0.62211	0.0258554	0.520746718
Iron ore	kg	1.20793	0.000000461	1.002581978
Iron and steel scrap	g	171.864	1137.18	335.96772
Electric power	kWh	0.35	0.35	0.35
Limestone	g	120.976	0.000231	100.4101193
Total primary	MJ	21.1217	2.3984	17.938739
Total	MJ	21.1217	21.1217	21.1217
MP	g	18.744	0.219157	15.59477669
CO_2 + CO	g	1,884.47	169.646	1,592.94992
CO	g	1.0248	1.32668	1.0761196
SO_x	g	4.15594	1.04022	3.6262676
NH_3 (l)	g	0.08077177	0.000606085	0.067143604
NO_x	g	1.419934	0.4528213	1.255524841
HC	g	15.586795	1.2328902	13.14663118
Solid residues	g	432.261	54.738	368.08209

Source: [54]

2.1 Automobile lifetime

The use of the automobile is characterized by the high amount of fuel consumed. The combustion is responsible for the emission of several air pollutants. Also, automobile use is associated with water consumption, for cleaning and cooling. Solid residues are also a result of this process due to parts exchange (either because of the end of the lifetime of the part or because of accidents).

From data provided by Petrobrás [46] it was possible to estimate the average lifetime distance travelled by an automobile in Brazil as 195,000 km. It was assumed an automobile uses gasohol (78% gasoline, 22% alcohol).

The lifetime energy consumption was estimated as 4.10 MJ/km (on average, 8.5 km/litre of gasohol). The national gasoline consumption in 1998 was 831.841 TJ [47]; at that time, the fleet was estimated as 16.5 million automobiles [48], corresponding to an average consumption of 50.4 GJ/year. Assuming that the average distance travelled by an automobile per year is 13,000 km, the annual consumption would be 3.87 MJ/km, 5.6% less than it was estimated for an automobile weighing 1,300 kg. However, it is important to note that in Brazil most automobiles are compact and weigh around 1,000 kg.

The SO_2 emissions are related to the amount of sulphur content in the fuel. Pedroso Jr. [55] estimated SO_2 emissions as 0.129 g/km for automobiles. In that study a sulphur content of 0.08% of gasohol and 10 km/litre as the performance figure of an automobile were used, which results in an average emission of 1.29 g/l of gasohol. As the average automobile considered in this study has a performance of 8.5 km/l (12.5 l/100 km), therefore it was estimated that SO_2 emissions were 0.152 g/km. These emissions were quite similar to those estimated by Cetesb [49], which resulted of 0.156 g/km in the Metropolitan Region of São Paulo. Emissions of CO, HC, NO_x and PM were also obtained from this source.

Lead emissions were estimated considering that there is 0.005g of Pb per litre of gasohol [46], which accounts for a 5.9 mg/km for the case studied.

Finally, carbon dioxide emissions were estimated supposing that gasohol is a mixture of C_8H_{18} and C_2H_5OH and that the combustion resulted in CO_2, CO and CH_4, that is, all hydrocarbons taken into account were methane. As CO and HC were available, CO_2 was obtained from the mass balance of the chemical reaction above.

$$C_8H_{18} + C_2H_5 - OH + O_2 \rightarrow CO_2 + CO + CH_4 + H_2O$$

Automobile lifetime environmental data are shown in Table 3.

Table 3: Automobile use environmental data

Environmental data	Unit	1998
Energy	MJ/km	4.1
Particulate matter	g/km	0.08
CO_2	g/km	191
CO	g/km	18.4
HC	g/km	1.6
NO_x	g/km	1.0
SO_x	g/km	0.16
Pb	g/km	0.005

2.2 Automobile assembling

Only one automotive industry published the environmental aspects, however only the electricity consumption (798 kWh/vehicle before and 550 kWh/vehicle after adopting Environmental Management System) and water consumption (8 m³/vehicle before and 4.5 m³/vehicle after adopting Environmental Management System).

2.3 Automobile discard

The amount of steel that is recycled in Brazil is 25% [50]. Admitting the same percentage for an automobile, the production of solid residues is 75%.

2.4 Interpretation

The contribution of the life cycle steps in the natural resources and energy consumption and air pollutants emissions due to

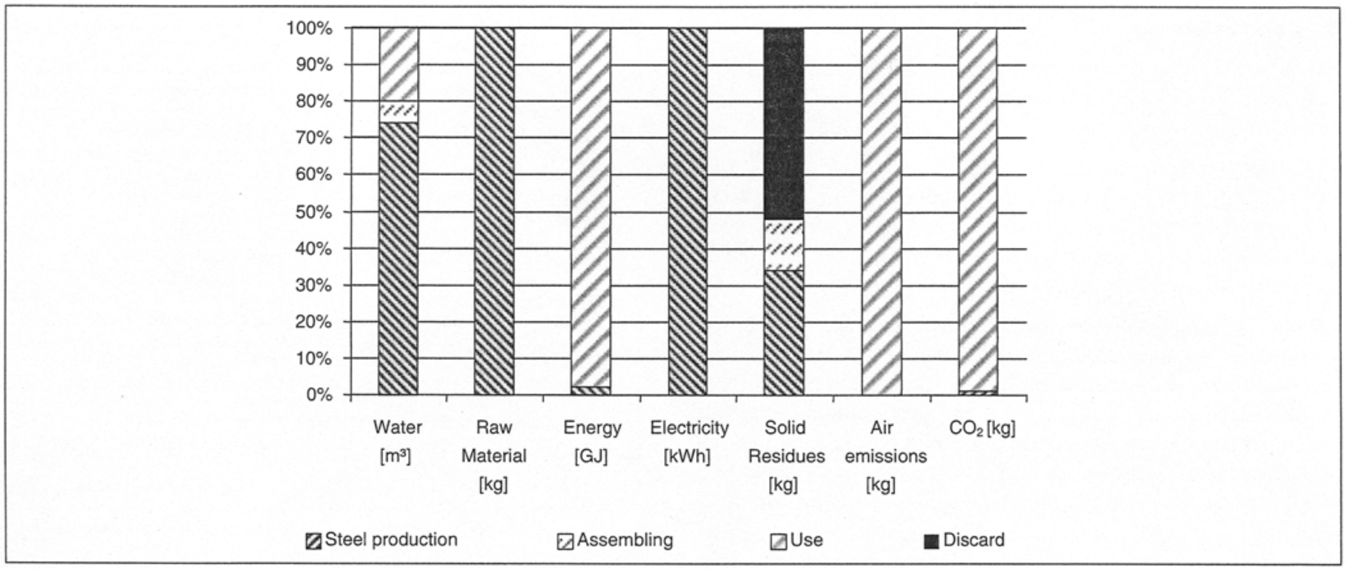

Fig. 4: Contribuition of the stages in life cycle inventory of steel in Brazilian automobiles

the utilization of primary steel in automobiles is shown in **Fig. 4**. The CO_2, CO, HC, NO_x, SO_x, Pb and PM emissions and the energy consumption occur mainly during the automobile utilization, while the electricity is basicallly consumed during the steel manufacturing. The production of solid residues was shared by materials manufacturing and disposition.

The results for the solid residues production and the electricity consumption might have been due to the lack of data in the automobile usage (for example, the solid residues produced by the tyre, the oil and parts discard and the electricity produced in the battery). A similar evaluation can be applied to HC and NO_x emissions, however, the lack of data was in the manufacturing and discard phases.

The participation of the automobile usage in resources consumption is even greater while considering the use of secondary steel. The main reason is that the latter consumes fewer resources than the former. Nevertheless, the contribution of CO, NO_x, SO_x, HC and Pb emissions are similar; these data are mainly from the automobile usage. Materials manufacturing, however, produces about 20% of the solid residues of the life cycle for the secondary steel and 40% within the use of primary steel.

Fig. 5 shows the differences obtained while considering Brazilian and US data of steel production. Although data was not from the same year, there was no pattern at all. For instance, while total energy were quite similar, particulate matter emissions were much higher while using US data, most probably due to system definition. The use of charcoal in Brazil also resulted in differences in coal consumption.

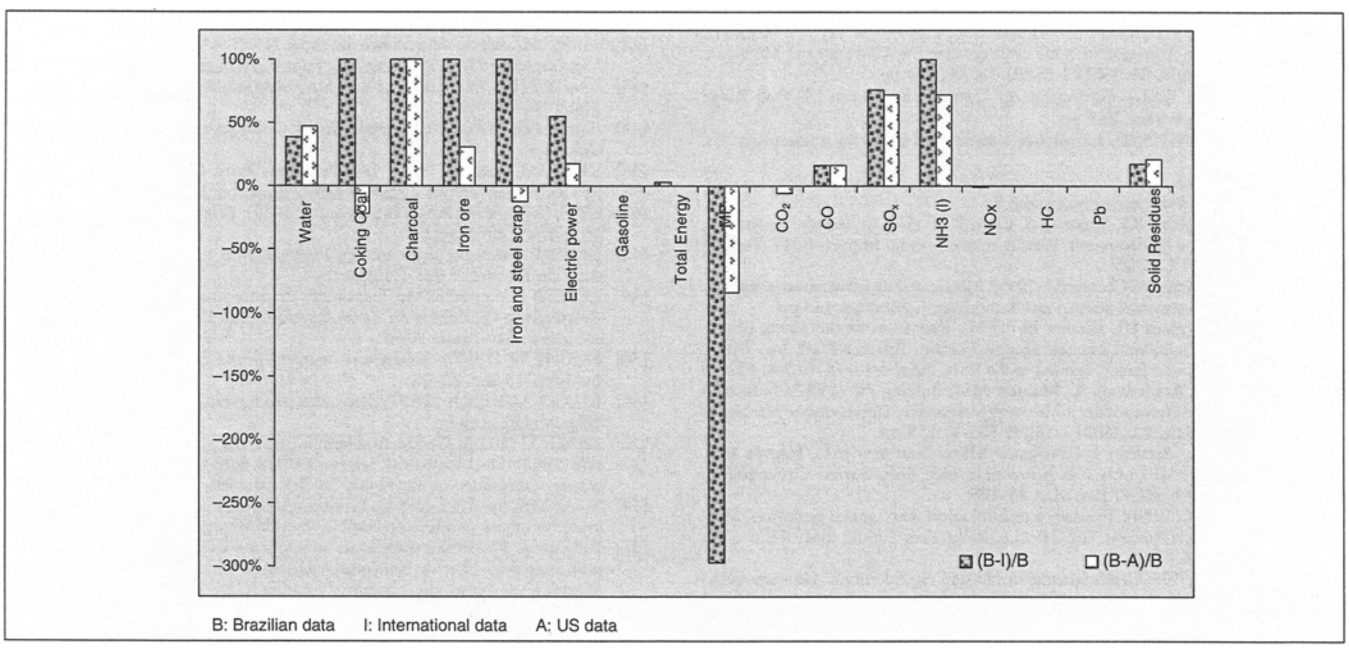

Fig. 5: Differences between Brazilian and USA data of steel production in the life cycle

3 Conclusion

A life cycle inventory for steel used in automobiles showed that the automobile use is mainly responsible for most environmental concerns considered.

The usage of secondary steel was especially beneficial, reducing not only the amount of solid residues by the end of the automobile lifetime, but also the amount of energy consumed and air pollutant emissions. The amount of steel recycled in the country is still very low – 25% acoording to [49].

On the other hand, as the weight of the material used in the automobile does not change and the use of the automobile is responsible for the greatest amount of pollution, the benefits of the use of secondary steel is concealed. This would suggest that the substitution for lighter materials would be a successful environmental choice. However, it is also necessary to develop a new life cycle of the substitute material to ensure the benefits.

However, at this time, it is not recommended to reduce the lifetime of the automobile, for two main reasons: i) the low rate of automobile materials recycling performed in the country and ii) the respective increase of the environmental concerns in other life cycle phases, just like the electricity consumption.

It is also important to add that the main difficulty in performing life cycle analysis is in obtaining data. Having a publicly-available national database would have been helpful.

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